MINIMIZATION OF NUMBER OF ACTIVE COMPONENTS FOR COMSOL'S THERMAL SIMULATION MODEL

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Abstract

The power electronic system which contains printed circuit board is comprised from set of passive and active components. Active electronic components are represented as source of thermal energy which arises from power loss of given device. By capturing the surface's temperature of whole electronic system through thermo vision measurement and by consequent picture analysis of thermo frames it is possible to identify active components. The aim of this article is development of methodology for optimal selection of mentioned active components for thermal simulation model, whereby main target of proposed algorithm is determination of value of power losses of selected active components. Determination of power losses is provided through utilization of COMSOL and Simulink interface, whereby main thermal simulation analysis is then provided in COMSOL.

1 Loss model of electronic system with PCB

Geometrical model of electronic device consists from set of passive and active components. Then the total number of components on PCB is:

$$n = p + a\,,$$

where,

p – is number of electrically passive components (they are accumulating, transferring and radiating thermal energy)

a – is number of electrically active components (instead of accumulation, transfer and radiation they are also considered as heat sources which are dissipating power loss of given component).

Each of components (active/passive) is identified during thermo vision measurements.

The active component with i-th order is heated by power loss $P_c(i)$. Power los sis then transferred to the heat and component and its surrounding will become warmer. The average value of temperature in 3D space of whole electronic system, which is heated just by i-th component with power loss $P_c(i)$ is given by:

$$\overline{T}(i) = \frac{1}{V}\int T(x,y,z)dV\,,\; i \in \langle 1, a\rangle\,. \tag{1}$$

$\overline{T}(i)$ – average temperature of total system, when i-th component is heated by unity power,

V – total geometrical volume of investigated system,

$\frac{1}{V}\int T(x,y,z)dV$ – volumetric integral of thermal field which is obtained through post processing of parametric thermal simulation in COMSOL.

For investigated irredundant thermal model only the components with the highest thermal capacity will apply to increase of average temperature of whole electronic system.

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$$\left[\frac{1}{V}\int T(x,y,z)dV\right]_i > T_{threshold}, i \in \langle 1, a\rangle \quad (2)$$

The value of temperature $T_{threshold}$ can be estimated by expert estimation.

During operation the component's temperature rises above ambient environment. The temperature inside of the component exceeds the temperature at the surface of component and during the steady state the applied electrical power $P_c(i)$ (matches the heat power $P_{Th}(i)$ which is dissipated to the ambient:

$$P_c(i) = P_{Th}(i), i \in \langle 1, a\rangle \quad (3)$$

Cooling mechanisms for one of the components are described on the Fig. 1. There are three types of cooling mechanism:

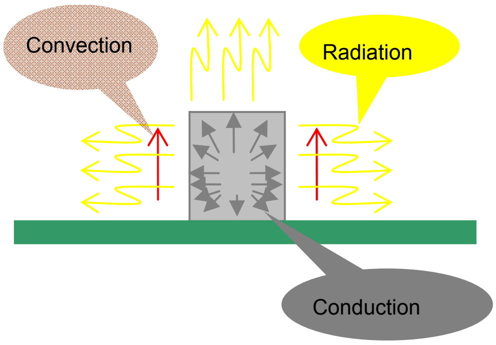

Fig. 1. Cooling types one of electronic component (i-th) on the PCB plate

- convection type (free or forces),
- radiation type,
- conduction type.

All types of thermal flows are able to be defined during setting of physical boundary conditions what is necessary for successful solution of thermal simulation.

To the each subdomain of power electronic module the physical-thermal coefficients have been defined using material libraries from COMSOL heat-transfer module [2]. Coefficient of PCB thermal conductivity creates tensor of 2nd grade in which part of axial and radial thermal conductivity are being included. The external subdomains of power electronic module are adjusted to complex convection and radiation of heat transfer according to next formula:

$$n(k\nabla T) = q_0 + h(T_{\inf} - T) + C_{const}\left(T_{amb}^4 - T^4\right) \quad (4)$$

By specification of q0 will represent a heat flux that enters the domain. $h(T_{\inf} - T)$ and is modeling convective type of heat transfer with the surrounding environment, where "h" is the heat transfer coefficient and $T_{\inf}$ is the ambient bulk temperature. The value of h depends on the orientation of specific side in ambient: vertical wall, horizontal plane downside, horizontal plane upside.

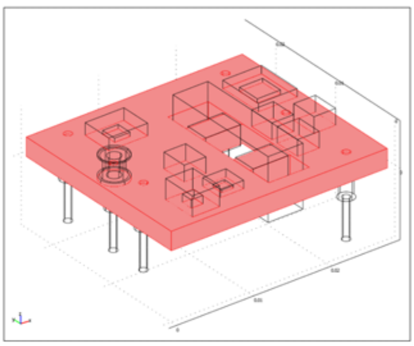

Fig. 2. 3D view on the PCB of DC-DC converter

$C_{const}\left(T_{amb}^4 - T^4\right)$ models radiation type of heat transfer with the surrounding environment. T_{amb} is the temperature of the surrounding radiation environment, which might differ from $T_{\inf}$. C_{const} is the product of the surface emissivity and ε the Stefan-Boltzmann constant $\sigma = 5.669 \cdot 10\text{-}8\ \mathrm{W/m^2K^4}$.

2 Simulation model of losses of switched mode power supply

The geometrical model of switched mode power supply with low power (20 W) is shown on fig.2. This electronic system consists of several IC devices (Fig. 3), capacitors (Fig. 4), inductors (Fig. 5), pads (Fig. 6) and of PCB which has 4 layers.

Based on thermo frames form experimental measurement of temperature distribution on whole system we have identified 29 components which are located both on top and bottom side of PCB (Fig. 7).

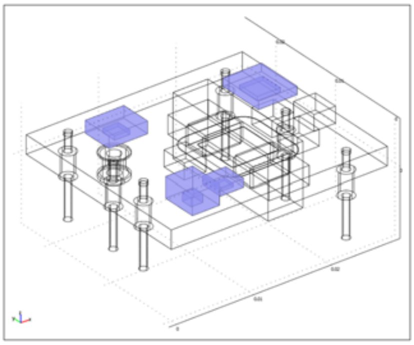

Figure 2. IC devices

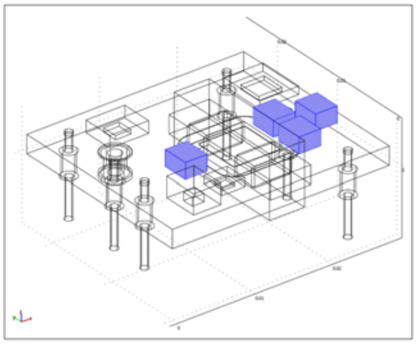

Figure 4. Capacitors

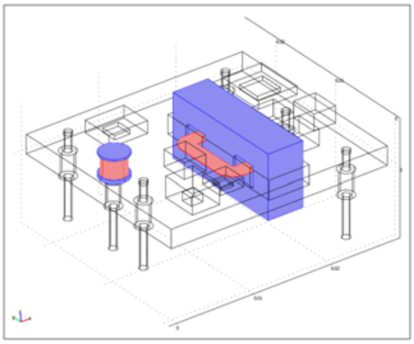

Figure 2. Inductors

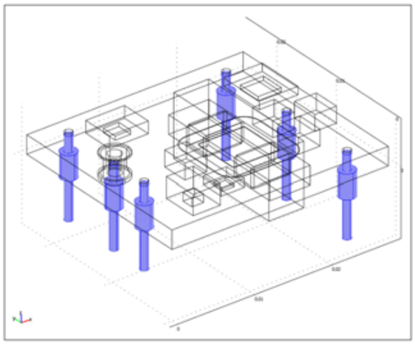

Figure 6. Pads of module

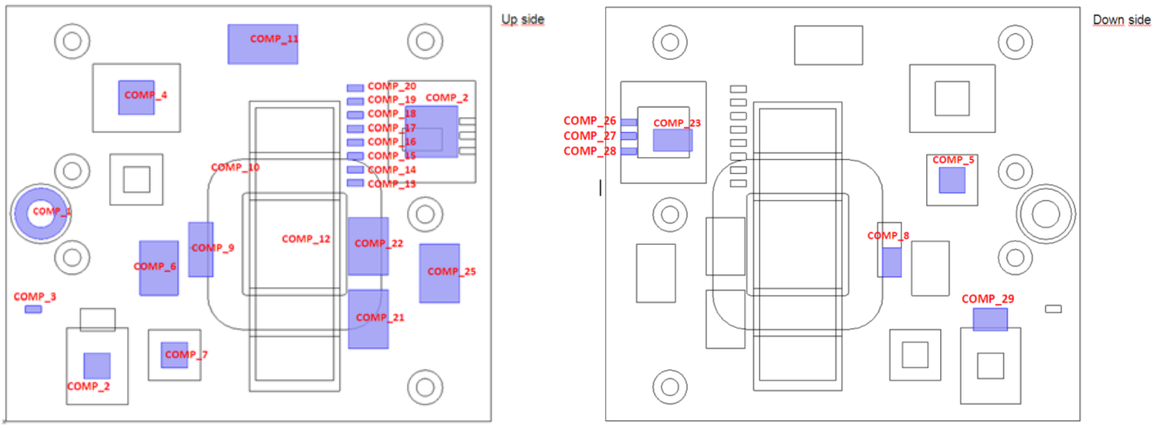

Fig. 7. Cooling types of electronic component i on the PCB plate

For identified active components of investigated system we have processed histogram of average temperatures of total system, which was heated separately by each component with power loss Pd = 1W according to next formula:

$$\overline{T}(i)=\frac{1}{2.236707e-6[m^3]}\int T(x,y,z)dV,\ i\in\langle 1,29\rangle \qquad (5)$$

Graphical interpretation of previous equation is on fig. 8. The red color marks temperature which is generated by component – winding of transformer. This component is heating total system in highest level compared to other components. Oppose to that, the core of transformer is heating total system at lowest level, what is marked by blue color. We have to note that several columns of histogram have been obtained from parametric simulation during which each component was heated by 1W, at the same condition as the other one (natural cooling).

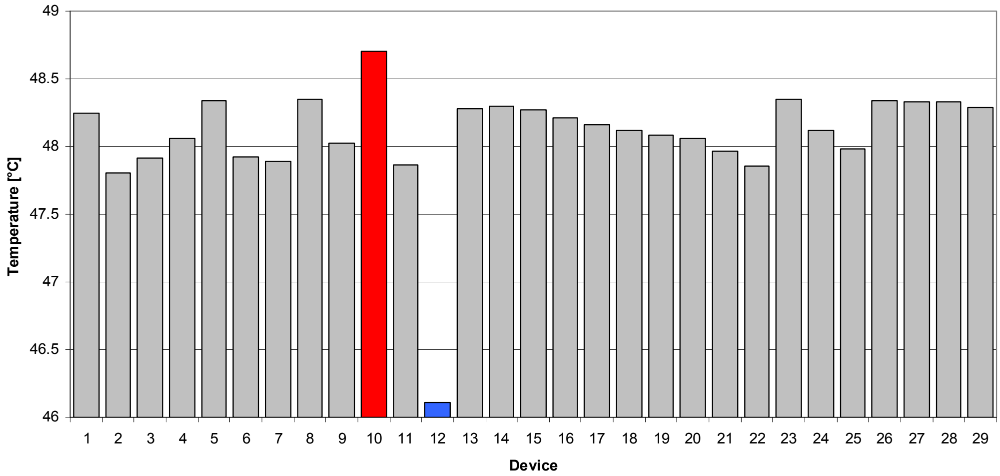

Fig 8. Average values of temperatures for several components during individual dissipation of each component by unity power (1 W).

The results from solution of equation (5) and (2) are shown on next figure (fig.9). The columns with grey color has the value of average value of temperature of total system, which is heated by one component with unity power loss (1W)

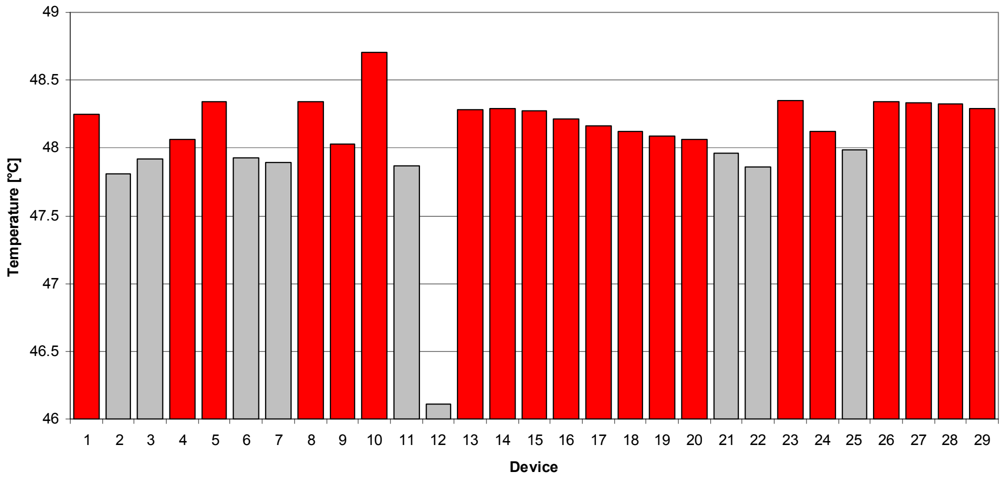

Fig.9 Histogram of average temperatures with set of active components for treshold temperature 48 ºC

Measured and simulated values of surface temperatures at given reference points from thermovision frames and at the points of geometrical model of switched mode power supply are creating good starting point for determination of power loss of selected components of whole electronic system.

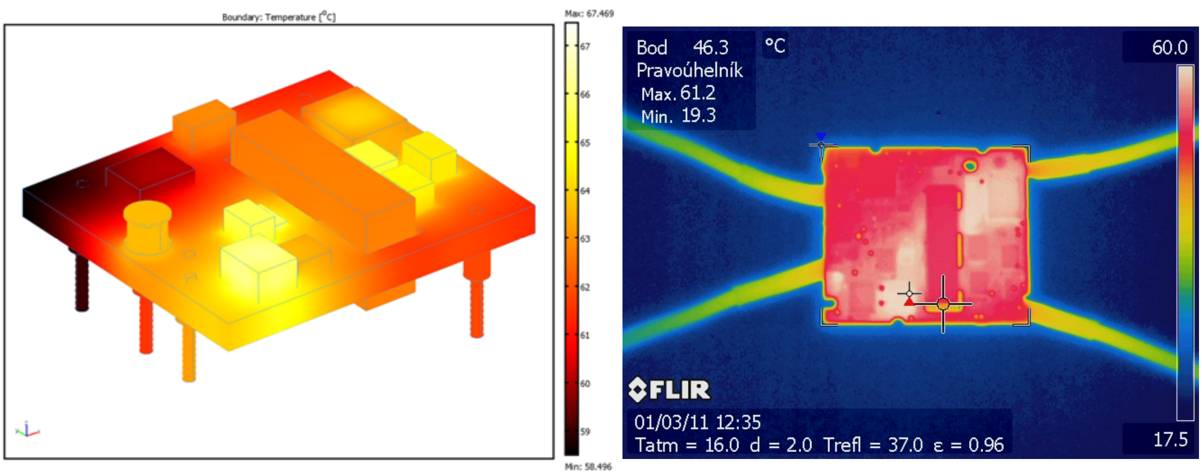

Fig. 10 Simulation results with utilization of deterministic algorithm of power loss experimental measurements

Results

The aim of optimization is identification of active components and definition of minimal set of components from set of active components {A}, in order to meet next relationship:

$$a_{\min} < a \, .$$

By elimination of component from set of active components {A} this becomes passive component. Such component in COMSOL won't have any power loss. The elimination criterion is determination of average temperature of whole system.

The main reasons for minimization of active components lie in necessity of optimization of simulation model what leads to faster computation and simulation time of temperature fields of investigated system. By presented process we are able to find irredundant model of power losses of electronic system, in which only components with the highest importance of average whole system's temperature rise are considered. Also very important is achievement of as lowest relative error between measurement and simulation as is possible.

Acknowledgement

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